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PL-TR-93-2007

NATURE OF CIRRUS

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23 December 1992

Final Report
1 March 1989-29 February 1992

PHILLIPS LABORATORY
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE, MA 01731-3010

Best Available Copy

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
23 December 1992

3. REPORT TYPE AND DATES COVERED
Final (1 Mar 1989-29 Feb 1992)

4. TITLE AND SUBTITLE
Nature of Cirrus

5. FUNDING NUMBERS
PE 61102F
PR 2311 TA G7 WU AA

Contract AFOSR-89-0320

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8. PERFORMING ORGANIZATION REPORT NUMBER

9 SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Phillips Laboratory
29 Randolph Road
Hanscom AFB, MA 01731-3010

Contract Manager: Frank Clark/GPOB

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
PL-TR-93-2007

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Software to extract IRAS-LRS spectra for any desired sky direction from the raw LRS data has been made. An exportable software system that allows to access, calibrate and process all IRAS data is available. It combines GIPSY (Groningen Image Processing System) and the GEISHA (Groningen Exportable Infrared Survey High-Resolution Analysis) system into one easily transportable user friendly system. All IRAS data are stored on a jukebox of optical disks. The whole system can remotely be accessed through e-mail at SRON-Groningen or can be used interactively.

14. SUBJECT TERMS
IRAS-LRS Cirrus
GIPSY
GEISHA

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18 SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

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Executive Summary

Introduction

The Infrared Astronomical Satellite (IRAS), operational in 1983, had three scientific instruments onboard. Best known is the photometric Survey Instrument, used in two modes: one performing long continous scans to perform the survey proper, the second repeatedly scanning a small region of sky. Always when the Survey Instrument was observing, the Low-Resolution Spectrometer (LRS) was also scanning the sky and gathering data. Downlinked from IRAS were a total of 2.3 Gbyte of LRS data and 11.1 Gbyte of Survey Instrument data.

Only a limited amount of the LRS data were available in 1989: the LRS 'Database', out of which the LRS Catalogue was created. On the request of the Astrophysics Program of the US Air Force's Phillips Laboratory (via grant AFOSR 89-0320), it was undertaken by SRON-Groningen to create a software system to have access to and to be able to analyse the full set of LRS data. The ultimate scientific goal of the grant was to establish, if at all possible, the nature of the IRAS-discovered 'cirrus', by combining many LRS spectra of bright cirrus knots and — hopefully — to discover telltale solid-state features in such a combined spectrum.

Creating a LRS access and analysis system

Selectively combining many spectra is only possible with *flexible* access to *all* LRS data. To allow automatic and fast access, all raw IRAS data were put on a jukebox of optical disks, and to provide a user interface, all IRAS data access and analysis software was integrated in an existing astronomical data reduction package, the Groningen Image Processing System (GIPSY). Two other products were developed, that significantly enhance the IRAS data processing capabilities: (i) an IRAS Pointed Observations data reduction package by Assendorp, and (ii) an High Resolution Analysis System (HIRAS) by Bontekoe and Kester. The latter system can be considered as an extension of the work undertaken for grant AFOSR 86-0140.

The Low Resolution Spectrograph (LRS) is a slitless prism spectrometer. As an object is scanned across the LRS aperture the wavelength of the radiation transmitted to the dectectors varies. Thus spectral information has been obtained for all sources crossing the LRS aperture. Since the dispersion direction is the same as the IRAS scanning direction, the detector output is a convolution of the source structure and spectrum. Sources larger than 15″ are effectively degraded in spectral resolution because of this convolution.

To be able to reduce the LRS raw data within GIPSY, the data have to be put in a special data format (designed and implemented by SRON/G), which has the IRAS bore-sight pointing information added to it. Going from raw data to actual calibrated LRS spectra involves a number of steps: (i) conversion to milli-Volts, (ii) correction for 'anti-drooping' and 'zero clamp', (iii) determining the in-scan and cross-scan distance of each sample to the source of interest, (iv) using the in-scan distance to determine the wavelength, and thus wavelength dependent corrections for each sample, (v) using the cross scan distance to determine cross-scan gain corrections, (vi) finally resampling the spectrum onto a regular wavelength grid for storage.

Scientific results

Before creating this LRS access and analysis system it was not possible to have access to and study LRS spectra of moving objects. Several types of such objects have consequently been studied.

In collaboration with another Phillips laboratory grantee, Dr D.K. Lynch, spectra of comet cores have been studied. These have temperatures which are typically of order several 100 K. Thus they are ideally observed in the infrared. The region of the spectral domain where silicate features can be found around 10–20 μm (in whic' '. ɜ LRS has operated) is well suited to study the composition of the cometary material. For the first time, good LRS spectra have been obtained for two comets, Tempel I and Tempel II. Both comets show a black-body spectrum with superposed a hint of silicate emission features.

Another study has been undertaken, for ESA, to extract data of fast moving 'orbital debris' objects in the upper Earth atmosphere from the IRAS database. In a few cases it was found that these crossed the focal plane in such a fashion that the LRS was also illuminated. The spectrum of one of those objects clearly shows a black-body type spectrum with a temperature of ~300 K.

The Rosette nebula was studied by Assendorp and Clark using both IRAS photometric and (LRS) spectral data. To generate reliable LRS spectra for such a confused region flexibility is very important. Only by looking in detail at the survey data it can be determined which LRS scans are liable to give good spectra and which are likely to be affected by confusion. Several reliable spectra for Rosette nebula sources could be generated by carefully selecting and calibrating individual scans which were not affected by confusion.

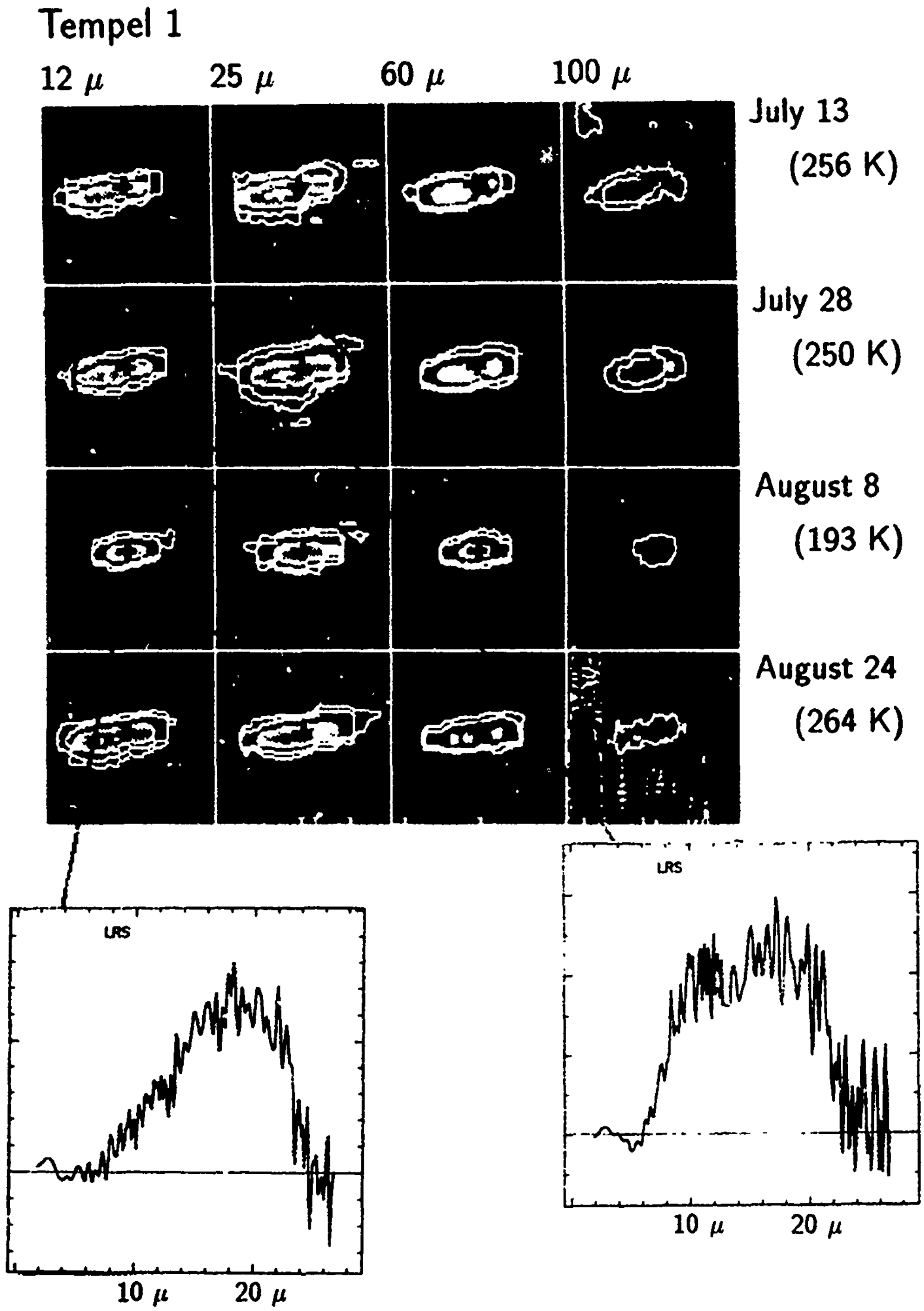
One of the aims of designing complete access to all LRS data was to generate spectra of, most likely very weak, cirrus features. It was the intention to use the access to *all* LRS data as provided with the server, to co-add LRS spectra for a large numb.. of positions towards which cirrus emission is seen. That this procedure is in principle feasible is shown with the results towards comets; several spectra for different sky positions are added together to generate a good average spectrum. Unfortunately the work done to date has shown that generating cirrus spectra is a very difficult task due to two effects.

Firstly, since the LRS dispersion is in the scanning direction, it only makes sense to try to generate spectra of cirrus features which are extended *only* in the cross-scan direction. For objects which are significantly larger than 15″ in the in-scan direction the LRS spectrum becomes a convolution of source structure and true source spectrum, and thus difficult to interpret. To date no such linear cirrus features have been identified.

Secondly much of the cirrus emission is weak. Thus 'zero-clamping' is a significant problem. Since zero-clamping occurs with a low constant or decreasing signal, only when the cirrus is superposed on a, spectrally featureless, background gradient can spectra be generated in a straightforward manner. Unfortunately the typical behaviour of the zero-clamp signal seems to indicate that this gradient must be at least a few Jansky per minute of arc. Thus the only large scale gradient in the IRAS data, the zodiacal light emission, is most likely not steep enough

Unfortunately, the otherwise very succesful project, has not been able to generate a spectrum of cirrus by combining thousands of low-intensity scans. We think it is unlikely that this can be done, because of the two problems mentioned above.

The Nature of Cirrus



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A mosaic of IRAS survey images of the comet Tempel 1 is shown together with two LRS spectra. The four columns of images correspond to the four IRAS bands at 12, 25, 60 and 100 μm. The different rows correspond to data taken at the different days in July and August 1983 as indicated. The comet underwent some sort of change between July 28 and August 8, which is seen as a significant decrease in the 12 μm brightness. The implied color temperatures suggest that the comet was actually cooler than in its quiescent state. The LRS spectra for July 28 and August 8 show that indeed the spectrum changes significantly in this period.

1 Introduction

The aim of project 'Nature of Cirrus' was to establish the nature of the 'cirrus' features found by IRAS. That goal might be reached by co-adding a large number of Low-Resolution Spectrometer (LRS) spectra obtained on 'strong' peaks or ridges of the cirrus.

Thus it had to be made possible to extract from the raw LRS database those 1.5 seconds worth of data that contains a LRS spectrum corresponding to a desired sky direction. It should be investigated whether it is feasible to co-add many very noisy LRS spectra in order to improve the signal-to-noise ratio of the combined spectrum. Secondly, a large number of such strong cirrus peaks or ridges should be identified in the IRAS data, and their co-addition should be attempted.

In the extensive report below the work resulting from the stated goal is described. It was necessary to follow several seemingly deviating, much time consuming paths, to arrive at the desired LRS data extraction and reduction system. The two major extra paths were: putting all IRAS raw data on a jukebox of optical disks, and creating an user-friendly environment by transferring the stand-alone IRAS software to the Groningen Image Processing System (GIPSY). As closely related 'extra's' the HIRAS system and a system for processing the pointed observations (PO's) are described as well.

The report is structured as follows. (i) a brief description is presented of the IRAS satellite (Sec. 2) and its scientific mission, (ii) the IRAS server and its use are described (Sec. 3), (iii) the main dish of the report is served: the LRS data reduction and analysis system (Sec. 4), (iv) several scientific projects executed using the new system are described (Sec. 5), (v) several non-LRS scientific applications of the IRAS data access and analysis facility are mentioned (Sec. 6), (vi) three appendices conclude the report.

2 IRAS

2.1 The mission

In 1983 the infrared astronomical satellite (IRAS) performed an almost complete all-sky survey. The infrared sky brightness was measured at 12, 25, 60 and 100 μm for $\sim$95% of the sky. The satellite was in a polar orbit, precessing by $\sim 1°$ per day thus being able to observe the whole sky in a few months time (see Figure 1a). During standard operation the telescope scanned the sky along small circles.

For each wavelength band the focal plane contained two arrays of detectors (see Figure 1b). These arrays were laid out such that the second array scanned the same area of sky 5 to 10 seconds later than the first array, giving redundant coverage on a seconds time scale. Since subsequent scans on the sky were partly overlapping, also confirmation of source detections on an hours time scale was obtained (for more details on IRAS see IRAS-ES; Beichman et. al., 1988). This physical design and observation strategy were chosen in order to optimally fulfil the prime goal of IRAS: obtaining a complete survey of celestial infrared point sources.

Apart from the standard scans, also a large number of Pointed Observations (PO, also known as Additional Observations, AO) were carried out. These were typically raster scans covering small areas ($2° \times 0.5°$) repeatedly.

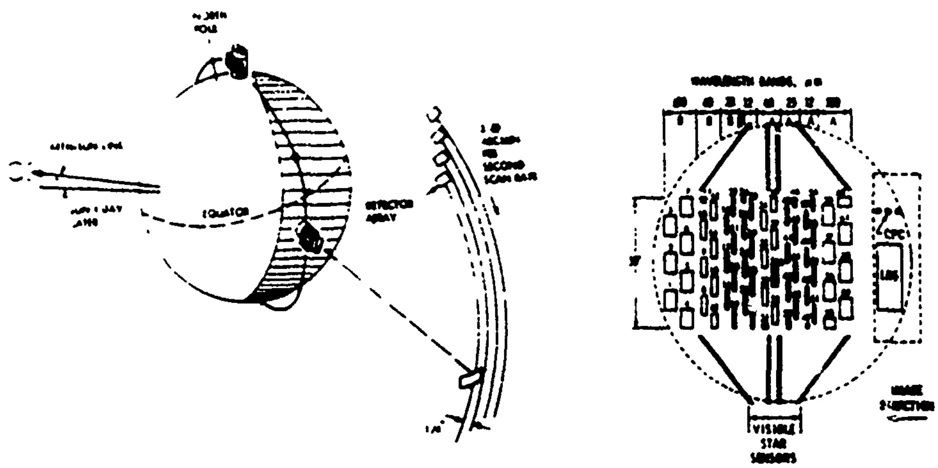

Figure 1: *IRAS.*
a) *Geometry of the IRAS orbit.* **b**) *IRAS focal plane layout.*

2.2 Data reduction and products

After the IRAS mission it was found that apart from yielding accurate point source positions and fluxes, the data quality allowed imaging of the infrared emission. As a consequence projects were started at two locations, the IRAS Processing and Analysis Center (IPAC) at Pasadena, USA, and at the Space Research Organisation of the Netherlands, Groningen (SRON/G), to generate calibrated infrared images of portions of the sky. At IPAC the emphasis was on generating a standard set of large plates (the Infrared Sky Sur· Atlas, ISSA), in Groningen most of the effort is directed towards special processing (high quality calibration, enhanced spatial resolution imaging, coadding of scans, LRS spectra).

Until recently only standard IRAS products (e.g. the ISSA plates and the LRS catalogue) have been available. However, in many cases an astronomer is interested in only the small area of the sky containing his favourite object. For this area of sky he wants access to *all* the IRAS data products (i.e. survey, LRS and PO's) in an interactive fashion. The IRAS server has been set up in Groningen to allow such access from an interactive system for analysis of astronomical data.

3 Access to all LRS data: the IRAS server

The access to and data reduction of IRAS LRS data should be seen as an extension of the existing Groningen Exportable Infrared System for High resolution Analysis (GEISHA), made for an earlier grant (AFOSR 86-0140). In spite of its name that system was not so easy to export and relatively user-unfriendly. Therefore, several changes of existing programs and the creation of new programs for the access and analysis of IRAS survey data were needed to create a versatile, exportable and user-friendly LRS access and data reduction system.

When we started the project, in 1989, GEISHA was running on a Cyber with operating system NOS and on a VAX under VMS; both university computers. It also ran, in a limited way, on our own UNIX computer and workstations. However, on each of these, the system was different, and only a very simple user interface was present. Only the Cyber could be used to extract the raw data from tape. A new Cyber was installed at that time with a completely different operating system, NOS/VE. We therefore decided to forget about Cybers (and also forgot about VAXes), and to transfer the complete GEISHA functionality to an UNIX environment under our own control.

At a very early stage, the Nature of Cirrus tasks were specified in detail by Roelfsema in ROG-DI-89-025. It was proposed to develop the LRS software within GIPSY. A study of different astronomical data analysis packages suggested that with its flexible data base system GIPSY was the most suitable environment for the calibration and analysis of IRAS data (see ROG-DI-89-026, Roelfsema, 1989). As a consequence SRON/G has been actively involved in the creation of a GIPSY version for UNIX, and has been responsible for defining the IRAS data structures and transferring the GEISHA programs to GIPSY.

As preparatory work for the transfer and upgrade of all GEISHA routines, Kester described standards to which the software should adhere in a note 'Software Quality Assurance' (ROG-DI-89-021). For all the phases of a software project (user requirements, analysis, design, implementation, transfer and maintenance) minimum demands on quality are prescribed. An investigation into existing software tools to apply the ideas of Kester's Note on real software systems led to the tentative choice of Cradle^{TM}. After experimenting with a test version for two months we decided that its functionality was too limited for our needs.

It was found that about 5% of the raw LRS data were not in Groningen. Therefore these data were requested from the IRAS Processing and Analysis Center (IPAC), and kindly sent to us.

3.1 Jukebox of optical disks

To facilitate the reduction of IRAS data, *all* survey and PO data for the 12, 25, 60, 100 μm bands and LRS, have been stored on an optical disk juke-box system (for 20 Gbyte) at SRON/Groningen, in 1991. This data transfer cost about 8 men-months of effort. (The jukebox and its associated work station were funded by the Dutch Astronomical Data Processing Centre.) Unfortunately, because of price considerations we had to restrict the jukebox capacity to 20 Gbytes, and therefore the IRAS data had to be compressed back to the actual format in which the data had been downlinked. When data are extracted, the expansion is carried out on-the-fly. Since the downlink compression scheme is used no data are lost in the compression/expansion steps. As a result the raw IRAS data for any on-sky area can now be accessed within minutes through a mail server (see appendix A).

A set of software tools has been constructed to extract, calibrate and generate images from these data. All the programs run in a batch mode under the GIPSY (see appendix C). The imaging and calibration programs can also be run interactively under the GIPSY. Using the Gipsy Data Subsystem (GDS) a four-dimensional internal storage format has been designed for IRAS data. The use of these IRAS Data Sets (IRDS, see section 3.2) in GIPSY allows the user to interactively inspect and edit raw uncalibrated IRAS data using standard GIPSY programs.

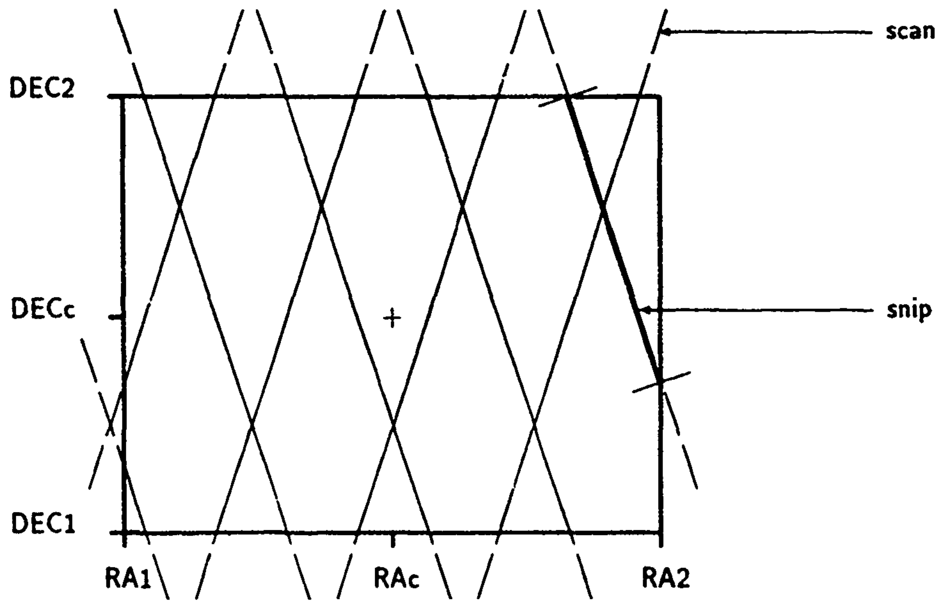

Figure 2: *The IRAS scans are cut into 'snips' for a GIPSY IRAS dataset corresponding to a user specified on-sky area.*

3.2 Raw IRAS data within GIPSY

Storing the raw IRAS data in a conceptually consistent fashion within GIPSY is a crucial part of the design of the IRAS server system. The raw IRAS data with all the ancillary information is not just a simple array of numbers. At SRON/G a 4-dimensional GIPSY data structure has been developed allowing a very convenient way to have access to raw IRAS data in a fully interactive processing system.

Due to the way in which IRAS has operated, the raw data for each detector consist of a series of data samples taken at constant time intervals at a rate of $N_{samples}$ per second or, more accurately, per satcal tick (the IRAS internal clock; one tick$\sim$1.00005 second). Once for every satcal tick housekeeping information such as the pointing direction of the satellite, the bore-sight information, is obtained. Thus for a section of a single scan (such a section is called 'SNIP' in the IRAS-GIPSY system, see fig. 2) of N_{ticks} satcal ticks for a given observing band (12, 25, 60, 100 μm or LRS) with N_{dets} detectors, the data can be viewed as a cube of $N_{samples} \times N_{ticks} \times N_{dets}$ pixels. Such a 3-D data structure is shown in figure 3. Note that the detector axis SDET doesn't have anything like a gridspacing or coordinate transform associated with it, it is an axis used only to order the data for the different detectors.

The SNIPs for a single wavelength band covering a given on-sky area can be collected in a 4-D structure (figure 4). Such an IRAS Data Structure (IRDS) then contains all data (samples

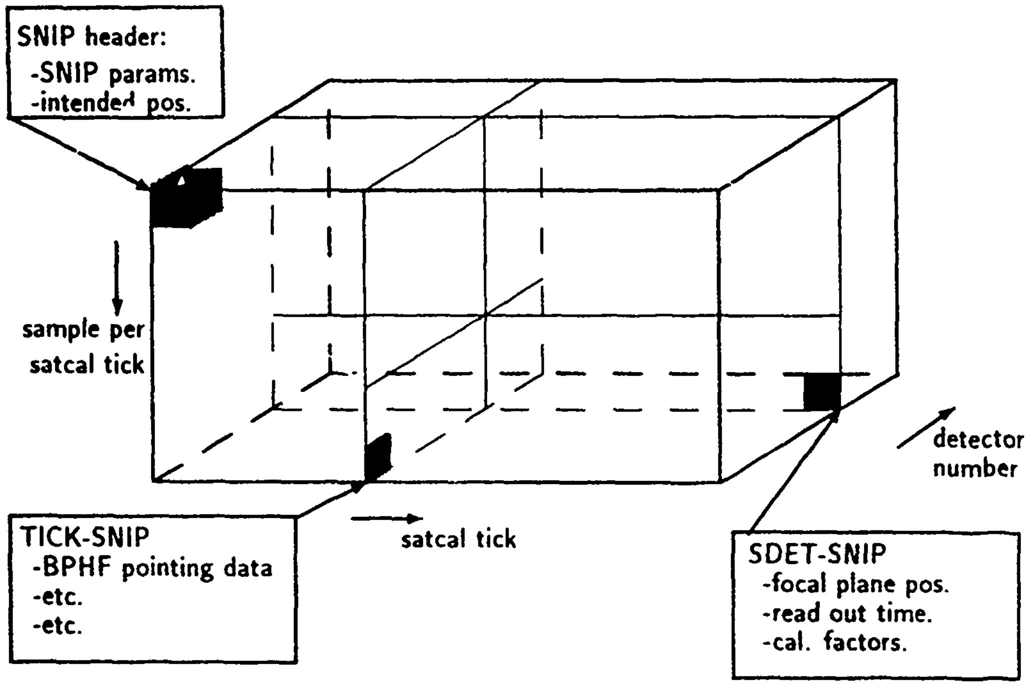

Figure 3: *GIPSY implementation of a single snip*

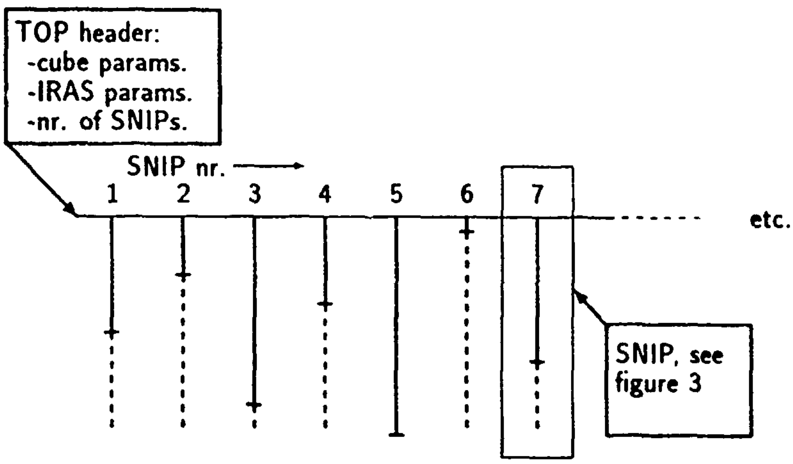

Figure 4: *A GIPSY IRAS Data Structure (IRDS)*

and position *and* calibration information) required to compute images, or, for LRS, spectra. The SNIP axis, like the SDET axis, is used only to order the snips.

Note that since an IRDS is a fully valid GIPSY data structure, *all* programs available under GIPSY can in principle be used on raw IRAS data.

The IRDS and its header is described in much more detail in the "IR-GIPSY programmers guide" (Roelfsema, 1990). This guide also contains descriptions of the vaiious interface and service routines designed especially for the reduction of IRAS data in GIPSY.

3.3 The IRAS data reduction process

The reduction and analysis of IRAS data roughly proceeds along the following lines: given an on-sky area of interest to the astronomer, the IRAS data relevant for that area are extracted from the IRAS data base and stored in an IRDS (see section 3.2) using the IRAS-GIPSY program PLATE. Thus the user receives only those sections (SNIPs) of the scans stored on the server which fall within the user selected area (see figure 2). Subsequently the bore-sight information is added to these data using RDBPHF.

These data next need to be calibrated and imaged. That is images must be generated in celestial coordinates for the survey data using IPACAL, ZODYCAL and IMAGE, and spectra for LRS data using LRSCAL. These steps may take some iteration, since the highest quality images are desired. In some cases superresolution ($\sim 1'$) may be needed which can be obtained using HIRAS. Both calibration and imaging is always done using the raw IRAS data as input. Only when the raw data are used it is possible to use newer, more accurate techniques for calibration and imaging.

Once the user is satisfied with the generated images, general GIPSY image analysis tools can be used for e.g. position measurements, flux measurements, line profile fitting etc. In some cases the image analysis results will point towards residual calibration problems, requiring the user to go back to the calibration/imaging step.

3.4 Server use

A system for remote access via e-mail to the IRAS-GIPSY system has been implemented by SRON/G in 1991. It consists of an HP 9000 and attached optical-disk jukebox. Since then, it has been used extensively, mostly in-house, but the number of outside users steadily increases.

	average	maximum	
Number of requests per day	15	25	
CPU time per request	6.4	21	minutes
Turn around time per request	1.8	25	hours
Average number of users in a month	24	30	
Nr. of requests per user	40	70	
Nr. of registerred users d.d. 10-12-'92	12	SRON	
	17	rest NL	
	10	rest Europe	
	5	USA	

Table 1: *Server use statistics*

Some of the statistics regarding the use of the IRAS server are listed in table 1. It is clear that the turn-around time is very good. Standard requests sent out can be expected to return results certainly within a few hours, often much faster (see table 1). When the high resolution imaging program HIRAS becomes available for more gereral use, a heavier load will be put on the server machine, resulting in a somewhat lower throughput. However, in the very near future an HP9000-730 is expected to take over for the running of calibration and imaging software which should again lead to a substantial speed increase.

Currently a time-limit is set on jobs, to make sure that users do not request a very large number of different images and/or spectra. Such large jobs might lead to excessive use of disk space, and would tie up the server for a single user for a long time.

3.5 Outside users

In 1992 the server facilities have been used by a large number of guests visiting SRON Groningen as can been seen from table 2. The table shows that guests typically stay for a few days to a week. Even in such a short stay, most guests learn to use the server and the GIPSY reduction programs without much assistance. In a number of cases the guests ported GIPSY to their own machine for further reduction following their visit.

Many of the scientific projects carried out during 1992 dealt with galactic astronomy: studies of stars and star formation region. In some cases (e.g. the search of Guglielmo for time variations in the Silicon feature of LRS spectra of circumstellar shells) even of order a hundred LRS spectra were generated within a week.

Name	Institute	from - to
Norman Trams	ESTEC-SSD	10 - 11 Feb.
Hans Plets	Leuven, Belium	early March
		7 - 10 Sept.
		28 Sept. - 2 Okt.
Bystrova	St. Petersburg, Russia	20 April - 5 May
Wim van Driel	Amsterdam, The Netherlands	19 - 20 May
Michael Braun	Jena, Germany	17 - 23 May
Xander Tielens	NASA-Ames, USA	14 - 21 June
Doug Whittet	Troy, Polytechnic Rensselaer, USA	14 - 28 June
Timo Prusti	Florence, Italy	14 - 28 June
Jeffrey Achtermann	Univ. of Texas, USA	22 June - 3 July
Mrs. Shylaja	India	29 June - 3 July
Francois Guglielmo	Meudon, France	6 - 10 July
Cheng-Yue Zhang	Univ. of Texas, USA	20 - 23 July
David Lynch	The Aero Space Corp., Los Angeles, USA	10 - 21 Sept.
Martin Cohen	Nasa Ames, USA	21 - 27 Sept.
Robert Stencel	U. of Colorado, USA	21 - 27 Sept.

Table 2: *Use of the IRAS server in 1992 by visitors to SRON*

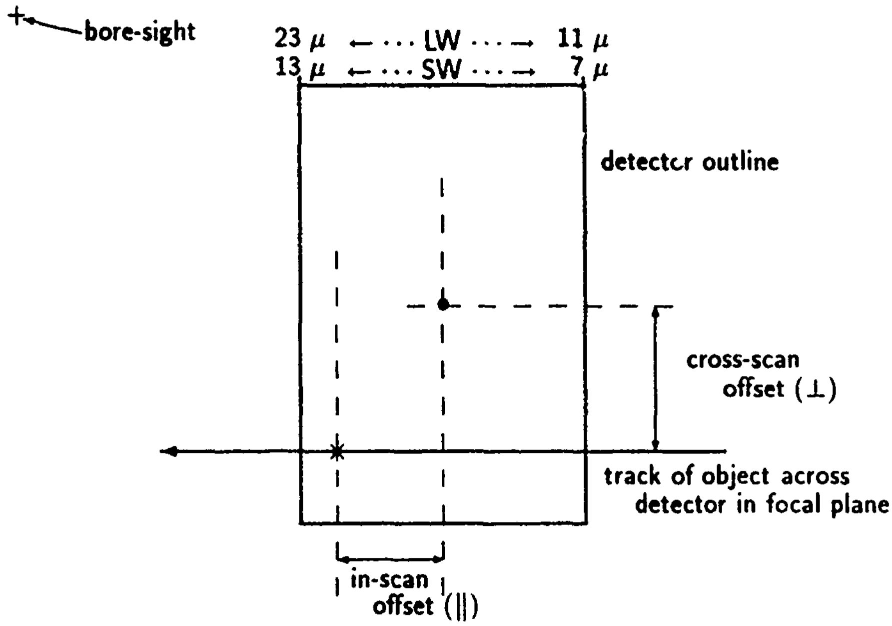

Figure 5: *An object crosses a LRS detector. The approximate wavelengths corresponding to the edge of the detectors is indicated for the short (SW) and long (LW) wavelength bands*

4 The Low Resolution Spectrograph

4.1 Instrument descript' ›n

The Low Resolution Spectrograph (LRS) is a slitless prism spectrometer. As an object is scanned across the LRS aperture the wavelength of the radiation transmitted to the dectectors varies (see figure 5). Thus spectral information has been obtained for all sources crossing the LRS aperture.

The LRS aperture has a size of $15' \times 6'$ (cross-scan × in-scan). The LRS contains 5 detectors; 3 short wave detectors sensitive to radiation from about 7.7 to 13.4 μm, and two long wave detectors for the 11 to 22.6 μm wavelength range.

The layout of the detectors in the LRS aperture is shown in figure 6. This figure shows how the short wavelength and long wavelength detectors are imaged onto the LRS aperture in the IRAS focal plane (figure 1b). The locations in the focal plane w.r.t. the bore-sight position and the in-scan and cross-scan sizes of the LRS detectors are listed in table 3. The table also lists the conversion factors from milli-Volts to $Wm^{-2}\mu^{-1}$ and timing information for the different detectors. The read time is the read out time offset with respect to the nominal satcal time of the sample due to the staggered reading of the different detectors. The delay is the total time delay introduced by the filtering of the signal. These timing parameters are used to reconstruct as accurately as possible the true on-sky position to which a given sample corresponds.

The LRS detector output is sampled at a rate of 32 Hz. With the IRAS scanning speed of $3.85'$ per second, this gives a wavelength resolution varying from ~50 at 8μm to ~20 at

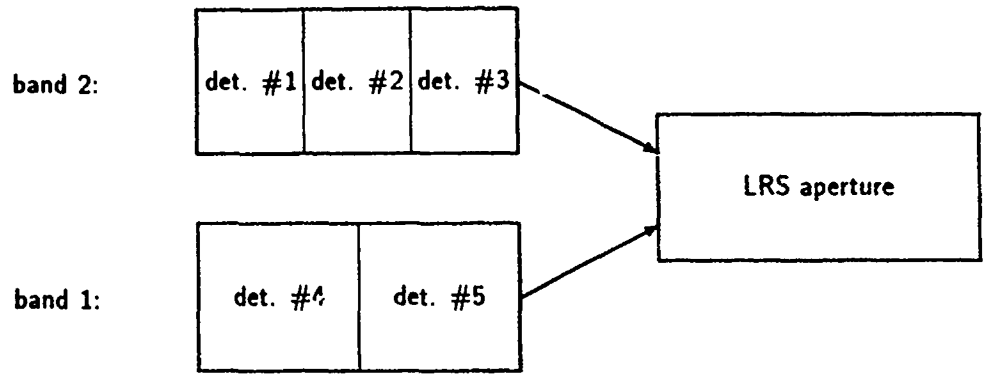

Figure 6: *LRS detector layout*

23μm.

Since the dispersion direction is the same as the IRAS scanning direction, the detector output is a convolution of the source structure and spectrum. With the sampling rate and spectral resolution of the LRS, spectra for sources smaller than 15″ are not affected by this convolution. For larger sources this convolution effectively degrades the spectral resolution.

A more detailed description of the LRS can be found in the IRAS-ES.

4.2 Calibrating LRS data and generating spectra

To go from raw data to actual calibrated LRS spectra a number of steps have to be taken. These steps have been implemented in the GIPSY program LRSCAL. LRSCAL expects the data to be in an IRDS (see section 3.2) which has the bore-sight data added to it. Such an IRDS can be generated using the server access programs PLATE and RDBPHF (see appendix A.1).

detector	λ	center position		size		read-time	delay	conversion
	(μm)	$\parallel$	$\perp$	$\parallel$	$\perp$	(sec)	(sec)	$Wm^{-2}\mu^{-1}/mV$
1	8-13	26.35′	-8.15′	6′	5.3′	0.052	0.0265	$1.87 \cdot 10^{-11}$
2	8-13	26.40′	-3.0′	6′	5.0′	0.048	0.0265	$5.33 \cdot 10^{-11}$
3	8-13	26.40′	1.85′	6′	4.7′	0.044	0.0265	$2.89 \cdot 10^{-11}$
4	11-22	26.50′	-7.35′	6′	7.5′	0.036	0.0265	$2.50 \cdot 10^{-11}$
5	11-22	26.45′	-0.15′	6′	7.5′	0.032	0.0265	$1.25 \cdot 10^{-11}$

$\parallel$ - in-scan, $\perp$ - cross-scan

Table 3: *Parameters of the LRS detectors*

What needs to be done is extract data numbers from the IRDS, convert these data to milli-Volts, correct them for the anti c rooping and zero clamp. Next the in-scan and cross-scan distances of each sample to the source of interest are determined. The in-scan distance is used to determine the wavelength, and thus wavelength dependent corrections for each sample. The cross scan distance is used to determine cross-scan gain corrections. Finally the spectrum is resampled onto a regular wavelength grid for storage.

In the following sections these various steps are described in some detail.

4.2.1 Data extraction

The first step is to extract the relevant data from the IRDS. This is done on the basis of a position specified by the astronomer. For all of the samples in the IRDS the distance to this position (in-scan and cross-scan see figure 5) is determined. These position offsets are calculated by interpolating the bore sight information from the header of the IRDS to the precise time at which the sample was taken. The sample time is calculated from the satcal of the given sample combined with the read-out time and electronic delay times (both listed in table 3). Thus the position offsets are based on the actual satellite pointing. The SNIPs (see section 3.2) for which for one of the samples this offset is less than the detector size (i.e. at that time the source illuminated the detector), are put in a list as candidates for further calibration.

4.2.2 Correction for high-pass filtering and zero clamping (anti drooping)

Following the data extraction from the IRDS, conversion from a logarithmic to a linear scale is the very first step of the processing of the raw data. In this step the data numbers as stored on the server are converted to the original detector output voltages (in mV).

Next the data are corrected for the high-pass filtering which occurred after the amplification stage. The detector voltage $V_d(t)$ at time t can be reconstructed from the measured output voltages V_o by equation 1.

$$V_d(t) = V_o(t) + \frac{1}{\tau_{hpf}} * \sum_{i=1}^{n} V_o(t_i) \qquad (1)$$

The time constant of the high-pass filter of the detector electronics (τ_{hpf}) was approximately 10 seconds. The term $\sum V_o(t_i)/\tau_{hpf}$ is a correction term corresponding to the accumulated charge on the capacitor in the filter. It is a continuous integration, in principle from $t = 0$ to $t = \infty$. However, since the capacitor in the filter was discharged whenever $V_o < 0$, the correction term in equation 1 must be reset to zero when this happens. In practice the term is reset if the sample voltage V_o drops below a 'zero clamp' threshold which is currently set to 0.1 mV. Since the signal went through filters *after* the clamp circuit, the actual level at which the clamp occurred, normally at noise peaks, cannot be reconstructed.

In practice the zero-clamp correction generates a saw-tooth like variation in the spectrum at low signal levels. Thus especially detections of weak sources become difficult. A spectrum generated by looking at empty sky is shown in figure 7. It clearly shows this saw-tooth-like variation.

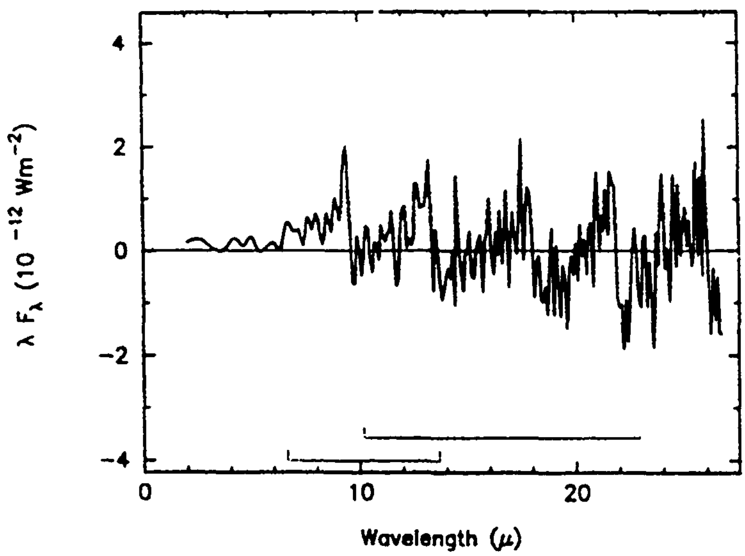

Figure 7: *LRS "spectrum" of blank sky*

Since the zero-clamp occurs at low (decreasing) signal levels it actually limits the sensitivity of LRS for sources on a decreasing or low background level. The effect cannot really be corrected for in a straightforward fashion. One possibility might be to actually fit the clamp behaviour using a saw-tooth with varying amplitude *and* varying period. This could be done e.g. using a simulated annealing (see "Numerical Recipes") technique.

4.2.3 Conversion of time based data to wavelength based data

The dispersion of the LRS optics is well described by a square root relation between position and wavelength. Thus the in-scan position offsets determined earlier can be used to calculate a wavelength for each sample. The relation between wavelength λ and in-scan position offset x with respect to the detector centre, used in LRSCAL, is given by equation 2.

$$\lambda = \lambda_0 + A \cdot \sqrt{x - x_0} \tag{2}$$

Note that since this is essentially a geometric problem the individual detector dependencies are taken care of by defining x to be the in-scan offset with respect to the detector centre. Since the two wavelength bands have different prisms and different light paths, each has its own set of constants.

Using planetary nebula data Olling (1988b) has determined very accurate values for the equation constants λ_0, A and x_0 for the short and long wavelength bands. The values of the wavelength scale constants for the long wave (LW) and short wave (SW) sections as used in LRSCAL are listed in table 4.

constant	SW section	LW section	units
λ_0	1.05	0.05	μm
A	4.613	8.368	$\mu m/\sqrt{arcmin}$
x_0	4.462	4.470	arcmin

Table 4: *Position to wavelength conversion constants*

4.2.4 In-scan distance dependent gain corrections

The voltages are corrected for in-scan distant dependent gain variations using a lookup table. These correction factors have been determined by a series of observations of asteroids and standard stars like α Tau. The asteroid spectra used for this purpose were assumed to be well represented by a black body curve. Since they are derived from spectra, in practice the correction factors are applied as a wavelength dep.. dent gain.

The correction factors used by LRSCAL are shown in figure 8. Figure 8 also shows an additional correction derived by Volk and Cohen (1989) based on a better model for the spectrum of α Tau. These extra correction factors can be applied if so desired.

4.2.5 Cross-scan distance dependent gain corrections

In order to correct for the cross-scan sensitivity variations of the detectors, correction tables of 16 entries (cross-scan position) per detector are used. The values used in LRSCAL are shown in figure 9. For each sample a correction factor is interpolated from the relevant table for the cross-scan distance determined earlier.

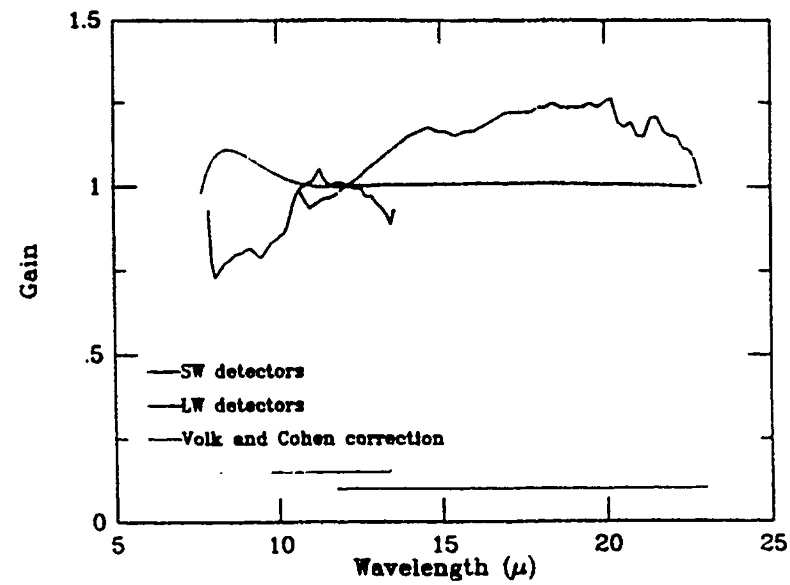

Figure 8: *LRS wavelength dependent gain correction*

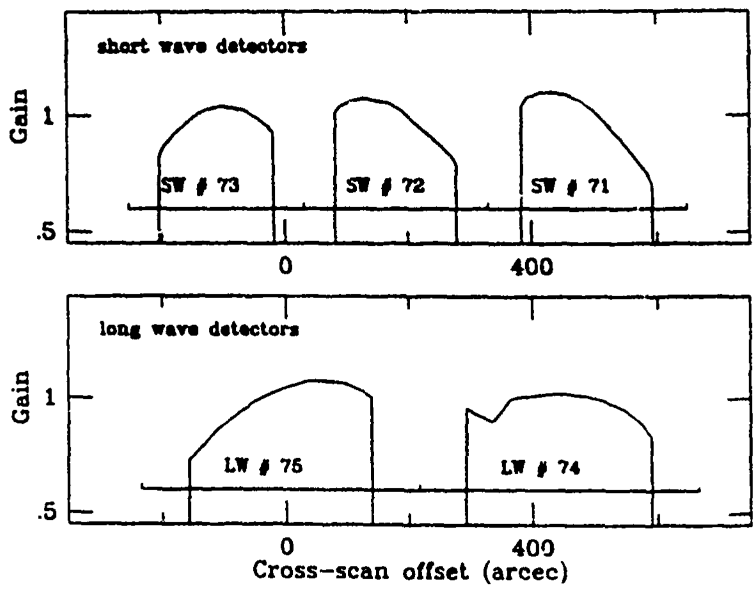

Figure 9: *LRS cross-scan gain correction*

When the cross-scan gain correction factor becomes large (a correction larger than e.g. 25 %), the source crossed very close to the edge of a detector. In this case the noise in the spectrum and, much more important, the uncertainty in the correcion factor, become rather large. Thus these data should not be used in the further processing.

4.2.6 Conversion to flux densities

Finally the data values are converted from milli-Volts to F(λ) in $Wm^{-2}\mu^{-1}$ by multiplying by a constant factor (conversion to other flux density units is also provided for).

The conversion factors used by LRSCAL are listed in the last column of table 3 above. By convolving a spectrum with the survey bandpasses at 12 and 25 μm, a comparison can be made with the Point Source Catalog flux densities: the agreement is generally good. For most sources agreement better than 10 % is obtained.

It has been investigated whether the response of the LRS detectors to the internal stimulators could be used for further refinement of the flux scale calibration. At the beginning and end of every scan the stimulators were turned on for 1 second (the 'flashes'), thus any sensitivity variations on a time scale of hours can be calibrated. It was found that the LRS detector response to the flashes is essentially constant throughout the mission, thus no correction based on flashes is applied.

Possibly in the future PSC data will be added to IRDS's, allowing this comparison to be done automatically.

4.2.7 Interpolation to a standard wavelength grid

The spectra generated from the different SNIP's are interpolated to an equidistant wavelength grid and subsequently added to obtain an average spectrum. This average spectrum, as well as the individual SNIP spectra can be stored in a standard GIPSY data set for later use. The individual spectra as well as their average are normally displayed on the terminal screen. They can also be plotted on a hardcopy device for later use.

Currently no effort is made to calculate correction factors based on the region of overlap between short wavelength and long wavelength halves of the spectrum. These are now combined by using only the shortwave data in the overlap region, since these have higher spectral resolution. An algorithm to do an actual match between the short- and longwave parts of the spectrum, which takes proper account of errors is under development.

5 LRS Projects

Some of the scientific LRS projects which are currently being carried out using the IRAS server facilities are given below. A number of those involve extracting data for non-stationary objects, which has not been possible previously.

5.1 LRS spectra of comets

Comet cores have temperatures which are typically of order several 100 K. Thus they are ideally observed in the infrared. The region of the spectral domain where silicate features can be found around 10–20 μm (in which the LRS has operated) is well suited to study the composition of the cometary material. Lynch, Lahuis and Roelfsema have extracted LRS data for a number of comets from the IRAS database. As a result, for the first time, good LRS spectra were obtained for two comets. Tempel I and Tempel II (see fig. 10). Both comets show a black-body spectrum with superposed a hint of silicate emission features.

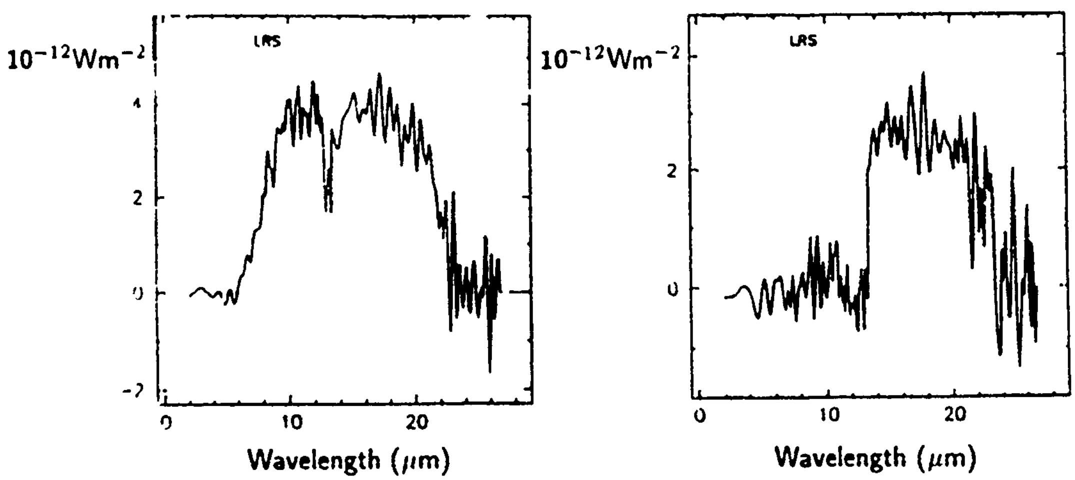

Figure 10: *LRS spectra of comets.*
a) *Tempel I.* b) *Tempel II.*

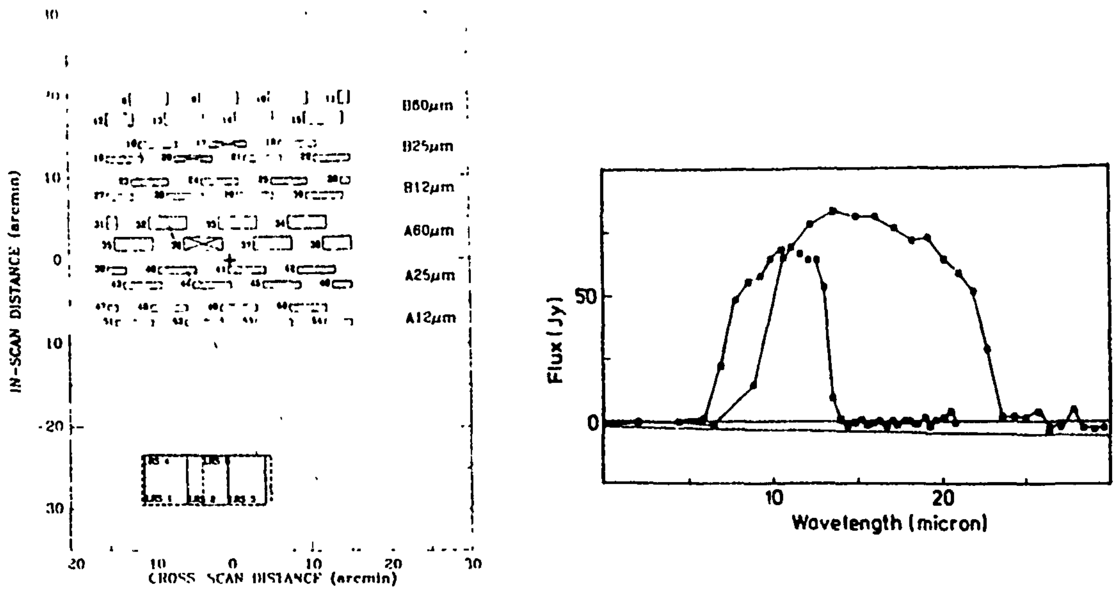

Figure 11: *Orbital debris.*
a) *Path across the focal plane illuminated by a typical orbital debris object.*
b) *LRS spectrum of an orbital debris object.*

The spectra for Tempel I indicate that it underwent an unusual outburst between July 27 and August 7, 1983. The brightness at 15 μm of the comet nearly doubled in that period, and the color temperature decreased from 260 K to 190 K. An LRS spectrum observed on August 23 showed the comet to be back in its quiescent state.

5.2 LRS spectra of orbital debris

At SRON Groningen a group led by Wesselius and de Jonge has been working on extracting data for fast moving 'orbital debris' objects from the IRAS database. These are objects moving around the earth at heights of up to a few 100,000 km. They are observed as sources crossing the IRAS focal plane at relatively high speed (up to 50-100 arcmin/sec) at angles between -90° and +90° with respect to the IRAS scanning direction.

The aim of the project is to study the size and temperature distribution of orbital debris objects orbiting earth. With the immediate access to the database such searches are relatively straightforward. In a few cases it was found that orbital debris objects crossed the focal plane in such a fashion that the LRS was also illuminated (see fig. 11a). The spectrum of one of those objects is shown in fig. 11b. It clearly shows a black-body type spectrum with a temperature of ~300 K.

5.3 LRS spectra in confused regions; the Rosette nebula[1]

The study of the ring-like HII complex the Rosette nebula in the IRAS survey bands was complemented with LRS spectra for individual sources (Assendorp and Clark). To generate reliable LRS spectra for such a confused region flexibility is very important. Only by looking in detail at the survey data it can be determined which LRS scans are liable to give good

[1]funded by the addendum to grant AFOSR 89-0329, requested on November 26., 1991

spectra and which are likely to be affected by confusion. Several reliable spectra for Rosette nebula sources could be generated by carefully selecting and calibrating individual scans which were not affected by confusion.

5.4 LRS spectra of cirrus features

One of the aims of redesigning the access to LRS data was to generate spectra of, most likely very weak, cirrus features. It was the intention to use the access to *all* LRS data as provided with the server, to add LRS spectra for a large number of positions towards which cirrus emission is seen. That this procedure is in principle feasible is shown with the results towards comets (section 5.1); several spectra for different sky positions are added together to generate a good average spectrum. Unfortunately the work done to date has shown that generating cirrus spectra is a very difficult task due to two effects.

Firstly, since the LRS dispersion is in the scanning direction, it only makes sense to try to generate spectra of cirrus features which are extended *only* in the cross-scan direction. For objects which are significantly larger than 15″ in the in-scan direction the LRS spectrum becomes a convolution of source structure and true source spectrum, and thus difficult to interpret (see section 4.1). To date no such linear cirrus features have been identified.

Secondly much of the cirrus emission is weak. Thus zero-clamping (see secion 4.2.2) is a significant problem. Since zero-clamping occurs with a low constant or decreasing signal, only when the cirrus is superposed on a, spectrally featureless, background gradient can spectra be generated in a straightforward manner. Unfortunatly the typical behaviour of the zero-clamp signal seems to indicate that this gradient must be at least a few Jansky per minute of arc. Thus the only large scale gradient in the IRAS data, the zodiacal light emission, is most likely not steep enough. Possibly the zero clamp problem can be solved by finding a "de-clamp" algorithm. Well chosen filters or a fitting-type operation might be suitable for this. By looking at the spectra of comet tails such a procedure could be tested. These tails are very long and, due to the IRAS scanning strategy, almost all perpendicular to the IRAS scanning direction. Finding and testing such an algorithm, although interesting, is by no means simple, and will take a substantial amount of time.

6 Other projects

6.1 Processing Raw Data of PO's

As a separate, but linked, effort software has been developed, mainly by Rob Assendorp, to combine the PO's made of a certain area of sky. This is by no means trivial, because the destriping of individual PO's is hard, due to the parallel nature of the scans. By first creating a map of an area using the survey data and then using it as a first estimate of the eventual PO map, software has been developed to combine PO data into much larger maps. Special software has been developed to extract information on source position and flux from such PO maps.

Assendorp, Boxhoorn, and Bekenkamp have applied the software to generate very low-noise images of the star formation regions Cha-I, Cha-II and R Cra. The various PO's were individually calibrated, and subsequently pasted together. When needed, slight position shifts were applied to individual PO's in the combination phase to correct for position errors. A destripe algorithm (Kester et. al., in prep.) was used to correct for detector gain variations. Due to the use of the PO data a significant reduction in the r.m.s. noise level was obtained.

6.2 High-resolution IRAS images[2]

The IRAS all-sky survey was designed and optimized for the detection of point sources. Therefore, the survey was conducted in the form of narrow strip scans with redundant coverage of the sky, but with non-uniform covering densities. Because of its much better quality than anticipated, the data shows in addition to point source, also sources of even very large extent, which are best analyzed from images. However, the non-uniform coverage now forms a significant obstacle in the image (re-)construction. Low resolution images, such as in the ISSA, yield spatial resolutions of 5–10 times the IRAS telescope diffraction limit. In principle, the data should allow images to be constructed, for most sky regions, at only 1–2 times the diffraction limit.

HIRAS is a GIPSY task which drives the MEMSYS5[3] maximum entropy imaging algorithm and is specifically designed for IRAS image construction.

In HIRAS the imaging equation

$$D = R * f \pm \sigma, \tag{3}$$

is solved. Here D is the data, f is the image, the matrix R describes the instrumental response, and σ is the estimated noise in the data. High demands are placed on the quality of the data and the response matrix R. Therefore, HIRAS utilizes the individual response functions of the focal plane detectors and rotates them according to the scan angle over the requested map. The noise is estimated for each individual sample using our knowledge of the data compression scheme used onboard the satellite.

The data D, in the form of scans, are first calibrated against a low-resolution map by the IMAGE task in GIPSY. After a first convergence of HIRAS, an higher-resolution image is obtained which in general still shows some residual striping. Small systematic effects are easily enhanced by the algorithm. The data then are again destriped in a fashion similar to the operation initially carried out by IMAGE. Subsequently a new maximum entropy solution to the imaging equation (equation 3 is determined, now using these re-destriped data. This cycle of destriping followed by determining the maximum entropy solution is carried out a number of times, until no further improvement in the image quality is obtained. In practice some 5 of these iterations yield images with a resolution of typically 30″ to 1′ in the 60 μm band.

Some examples of HIRAS results are shown in figures 12 and 13. In figure 12 a 60 μm image of the Andromeda nebula M 31 as generated using HIRAS is shown. The resolution in this image about 1′ , which is an improvement in the resolution of a factor 5 to 10 with respect to normal coadds as in the ISSA. It can be seen that the ring-like of M31 contains several very

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[2]contributed by: Tj. Romke Bontekoe, European Space Agency - ESTEC, Astrophysics Division, Postbus 299, 2200 AG Noordwijk, The Netherlands. The work described was done in collaboration with Kester.

[3]MEMSYS is a trademark of Maximum Entropy Data Consultants Ltd. Cambridge, UK

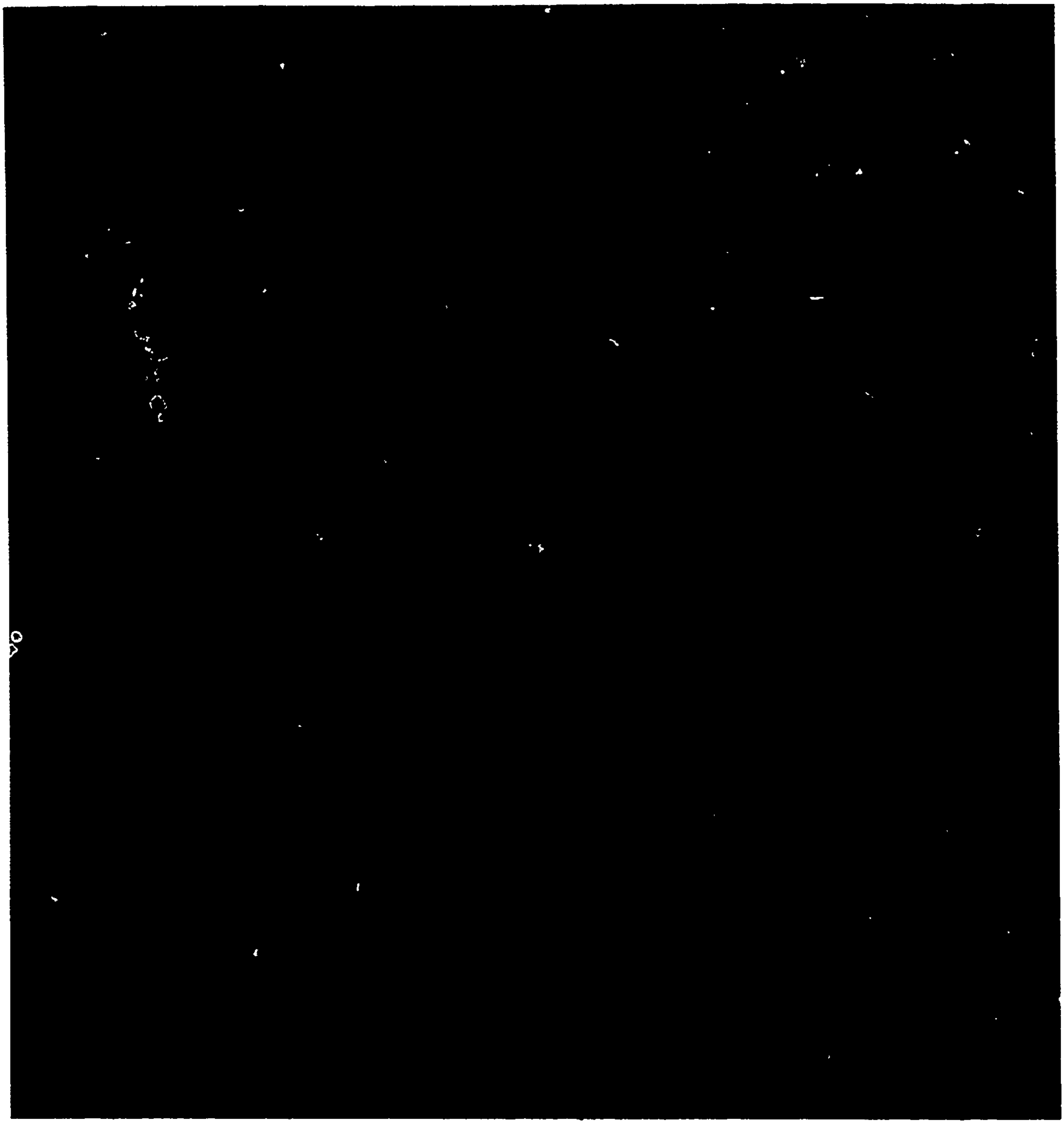

Figure 12: *The Andromeda Nebula (M31) at 60 μm as processed by HIRAS. The size of the image is 2.8° . The resolution is about 1′ (factor 5 to 10 higher than in normal coadds). Some residual noise is visible in the scan direction (from lower left to upper right). This is due to the digitization on board the satellite and forever lost.*

bright point sources (HII regions). Actually the brightest point is on the ring and not at the center of M 31. Unfortunately there are only two, almost parallel, complete coverages over most of M31. As a result the image restoration for this object is rather difficult. Residual noise is visible in the scan direction (from lower left to upper right). This is due to the digitization on board the satellite.

Figure 13 shows a composite of infrared, radio continuum and CO images of M 101. The comparison the 60 μm ISSA and MaxEnt images (figs. 13a and b) shows a clear improvement

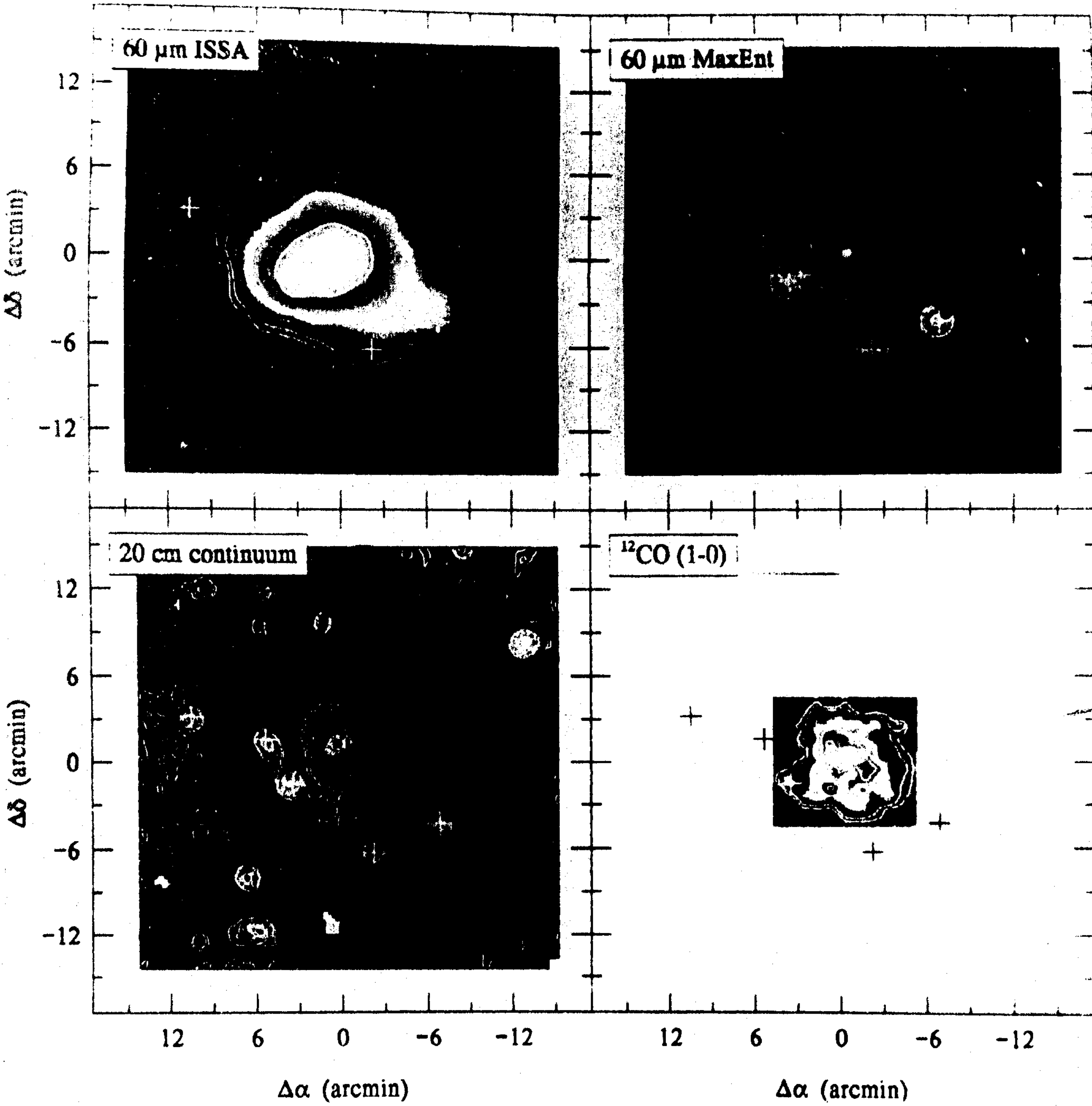

Figure 13: *Mosaic of images of M 101 (RA=14*^{h}1^{m}30^s*, Dec=+54° 35′ , 1950), produced by Enrico Koper (Leiden University). The crosses indicate the Faint Source Catalog positions of the five giant HII regions NGC 5447, 5455, 5461, 5462, and 5471.*
a) *60 μm ISSA: contours are at 0.5, 1, 2, 4, and 8 MJy/sr; the angular resolution is of the order of 5′ .* **b)** *60 μm MaxEnt: Maximum Entropy image constructed from IRAS 60 μm survey data. The image has been flat-fielded; contours are at 1, 2, 4, 8, 16, 32, and 64 MJy/sr; the resolution is of the order of 1′ in the areas of highest intensity.* **c)** *20 cm continuum: Radio continuum data of Condon (1987, 1989), taken with the VLA. Contours are at -2, -1, -0.5, 0.5, 1, 2, 4, 8, 16, and 32 mJy/beam; the resolution is 0.8′* **d)** *^{12}CO (1-0): Single-dish CO survey of Kenney et. al. (1991), taken with the NRAO 12 m dish at Kitt Peak. Contours are at 0.5, 1, ~~2~~ 3, 4, 5, and 6 K km s; ~~the~~ resolution is 0.9′*

in resolution. The crosses indicate a series of giant HII regions in M 101 which evidently are detected in the radio continuum, but also in the Ma::Ent image.

In HIRAS the spatial correlations in an image are controlled via a new multi-channel method, pyramid images, in which different spatial frequencies are represented in different images. As an example a image of 64×64 pixels can be constructed by summing a 64×64, a 32×32, ..., a 2×2, and a 1×1 pixel image from such a pyramid. In each of these images the total field size is the same while it contains information for one spatial frequency only. This approach clearly also allows the generation of images which contain information only corresponding to a selected range of spatial frequencies.

One of the problems of IRAS image reconstruction is that there is a significant possibility of amplification of the noise in the data, due to the ill-conditioned nature of the inversion of the imaging equation. All image reconstruction techniques suffer from this noise amplification. In HIRAS the behaviour of the noise can be visualized, sinc the an error map, having identical dimensions to the requested map, can be computed. This error map represents a full propagation of σ through the inversion of the imaging equation. Comparing the image with the error map gives indispensable information about the authenticity of detailed features. For example, the flux of point sources, determined from HIRAS maps is usually to within the HIRAS-estimated error the same as in the IRAS Point Source Catalog.

6.3 Other projects

Some of the other projects which are currently being carried out at SRON/G using the IRAS database server are;

- Cox and Roelfsema are investigating the properties of η Carinae in detail. Images in the four IRAS bands have now been constructed. This source is problematic due to its high brightness. In the imaging stage care has been taken to properly handle those parts of the data where the detectors were saturated due to the high signal levels. LRS spectra are currently being generated.
- Van Driel, de Graauw, de Jong and Wesselius have analyzed the available CPC images of galaxies. As a result, for some 50 galaxies which were not resolved spatially with the survey instrument, reliable images at 50 and 100 μm have now been generated.
- Currently a project starts to examine all LRS data from PO's directed towards external galaxies (de Graauw, Roelfsema).

A Access to the IRAS server

Registered users can obtain data from the IRAS server by sending a mail containing a request to **iras_server@sron.rug.nl**. To register as an official IRAS server user a registration request (e.g. *'Please register me, John Doe, as an official IRAS server user'*) must be sent to the same address. A mail request for data consists of a series of GIPSY commands, between double quotes, to be executed by the server. A description of GIPSY commands can be found in the GIPSY documentation. Sending the command **help** will cause the system to reply with the help file for standard IRAS server products. This documentation should suffice for most standard use of the server.

Once a request is sent to the server, it will first verify whether the request is syntactically correct. If so, the user will be notified by e-mail that the request is being scheduled for processing. Once the request is finished, again a mail will be sent to the requestor informing him/her of the result. In this mail the user will be told whether the request was successful, and how to get his/her data (if any) through ftp. After transporting the data to a local machine the user can process it further using his own preferred reduction system.

A.1 Getting an LRS spectrum using the server

Properly calibrating LRS spectra needs to be done interactively. Especially for weak sources user interaction is needed to judge the data quality. Only obtaining the raw data is done through the IRAS mail server. The example below shows a typical example of a mail request for LRS data for one source.

"plate instrume=survey lrs center=19h33m55.6s +19d25m40s size=1

coor=equ 1950 irset=ir19339+1925 object=19339+1925 observer=Guglielmo"

"rdbphf irset=ir19339+1925"

In this case the LRS data for a 1° by 1° area around IRAS 19339+1925 at RA $19^h33^m55.6^s$ DEC 19°25′40″ (1950) are requested. The selected data are to be stored in an IRDS named **ir19339+1925**. The second command tells the system to add the bore-sight pointing information to that IRDS. To obtain a good calibration for the spectra the bore-sight pointing information is essential.

This IRDS should subsequently be ftp'd to the users own machine where he/she can generate calibrated spectra using LRSCAL as sketched above.

B Standard acknowledgement

All IRAS server users are requested to put the following acknowledgement in material referring to the use of the SRON IRAS server data base:

> *The IRAS data were obtained using the IRAS data base server of the Space Research Organisation of the Netherlands (SRON) and the Dutch Expertise Centre for Astronomical Data Processing funded by the Netherlands Organisation for Scientific Research (NWO). The IRAS data base server project was also partly*

funded through the Air Force Office of Scientific Research, grants AFOSR 86-0140 and AFOSR 89-0320.

C GIPSY

The Groningen Image Processing System (GIPSY) was conceived in the early seventies to analyse the radio interferometric data from the Westerbork Synthesis Radio Telescope (WSRT). Over the last two decades it has undergone many changes and extensions, the last of these being a major overhaul and a port to UNIX. The current version of GIPSY is set up to be a highly interactive environment for the reduction of various types of astronomical data. The system is supported for Sun-4, HP9000-300, HP9000-700, Alliant FX and DEC MIPS. GIPSY makes extensive use of the X11 protocol, thus the consoles of the computers listed above as well as X-terminals can be used to run the system and for display. GIPSY can also be run from a VT100 compatible terminal. The system can be obtained through anonymous ftp from astro.rug.nl.

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